

FIRST EVIDENCE FOR $B_s \rightarrow \phi\phi$ AND PENGUIN B DECAYS AT CDF

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We present the first evidence of the decay mode $B_s \rightarrow \phi\phi$ and a measurement of partial width and direct CP asymmetry for the $B^+ \rightarrow \phi K^+$ decay using 180 pb^{-1} of data collected by the CDF II experiment at the Fermilab Tevatron collider. We measure: $\text{BR}(B_s \rightarrow \phi\phi) = (1.4 \pm 0.6(\text{stat.}) \pm 0.2(\text{syst.}) \pm 0.5(\text{BR})) \cdot 10^{-5}$, where the last error is due to the uncertainty on the $B_s \rightarrow J/\psi\phi$ branching ratio used as normalization, $\text{BR}(B^+ \rightarrow \phi K^+) = (7.2 \pm 1.3(\text{stat.}) \pm 0.7(\text{syst.})) \cdot 10^{-6}$ and $A_{CP}(B^+ \rightarrow \phi K^+) = -0.07 \pm 0.17(\text{stat.})^{+0.06}_{-0.05}(\text{syst.})$. We also briefly discuss prospects for studying other charmless $B \rightarrow VV$ decays at CDF

Several precision measurements on $B_{u,d}$ meson decays are available, yet many crucial theory predictions on B_s mesons, including mixing, CP violation and the decay width difference, $\Delta\Gamma_s$, are still to be tested. $B_s \rightarrow VV$ decays offer insights to both CP violation and $\Delta\Gamma_s$ thank to the presence of CP-odd and CP-even components in the decay amplitude. $B_s \rightarrow \phi\phi$ decays are the first charmless $B_s \rightarrow VV$ to be observed. This channel has been considered extensively in the literature ¹, even as a probe for New Physics along with other B_s modes. A recent calculation ² predicts a branching ratio of $3.7 \cdot 10^{-5}$. In the Standard Model (SM) the decay is mediated by $b \rightarrow s\bar{s}s$ penguin amplitudes which have shown discrepancies with the SM predictions, confirmed by recent data, for certain CP asymmetry measurements ³. $B^\pm \rightarrow \phi K^\pm$ decays are mediated by the same quark-level transition and have been already studied at B-factories ⁴. Measuring precisely rates and CP violation parameters in as many such decays as possible may help in determining the source of the above discrepancies.

We report the first evidence of the $B_s \rightarrow \phi\phi$ decay and the first measurement, at hadron colliders, of CP-averaged BR and direct CP asymmetry (A_{CP}) for $B^+ \rightarrow \phi K^+$ (charge conjugate modes are implied here unless otherwise stated). In order to cancel the production cross section uncertainty as well as to reduce the

systematic uncertainty on detector efficiencies, the branching ratios are extracted from ratios of decay rates of signals and well known B decay modes. In particular $B_s \rightarrow J/\psi\phi$ and $B^+ \rightarrow J/\psi K^+$ decays, characterized by the same number of secondary vertices and charged tracks in the final state as our signals, were used respectively in the $B_s \rightarrow \phi\phi$ and $B^+ \rightarrow \phi K^+$ analysis.

For this measurement we rely on the precision measurement of charged particle trajectories reconstructed in the central drift chamber (COT) and the silicon detector (SVX II). A complete description of the CDF II detector can be found elsewhere ⁵. The dataset used here was collected by the displaced track trigger, which is based, at Level 1, on the eXtremely Fast Tracker ⁶ and, at Level 2, on the Silicon Vertex Tracker ⁷ devices. The trigger selection is described in detail elsewhere ⁸. In addition a trigger with relaxed requirements was part of the trigger menu with a prescale factor automatically adjusted to fill the DAQ bandwidth available at low instantaneous luminosity. We use 180 pb^{-1} of integrated luminosity, and effectively only 100 pb^{-1} for the prescaled trigger.

In this analysis we have used $\phi \rightarrow K^+ K^-$ and $J/\psi \rightarrow \mu^+ \mu^-$ decays. Combinations of three or four tracks with $p_T > 0.4 \text{ GeV}/c$ are fit to a common vertex. At least one pair of tracks must satisfy the trigger requirements (trigger tracks). To isolate $J/\psi \rightarrow \mu^+ \mu^-$ de-

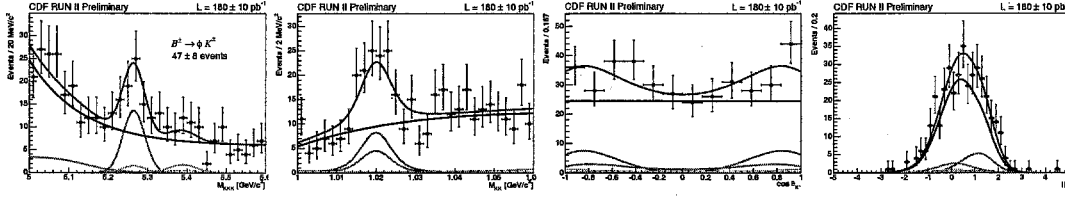


Figure 1. From left to right B mass (m_{KKK}), ϕ mass (m_{KK}), ϕ helicity and kaon dE/dx distribution of $B^+ \rightarrow \phi K^+$ candidates along with likelihood projections for: signal (red); $b \rightarrow \phi X$ (magenta); combinatorial background (black); $B^+ \rightarrow f_0(980)K^+$ (green); $B^+ \rightarrow K^{*0}\pi^+$ (light blue) and total (blue).

cays at least one muon must be identified in the muon detectors.

Combinatoric background is reduced by exploiting the long lifetime and hard p_T spectrum of B mesons and the isolation of b -hadrons inside b -jets. Requiring the B flight direction to point back to the primary vertex decreases background from partially reconstructed decays and selecting good quality vertices background from mis-measured tracks. The cut values on the discriminating variables were selected maximizing $S/\sqrt{S+B}$ for the already observed $B^+ \rightarrow \phi K^+$ signal, and maximizing $S/(1.5 + \sqrt{B})$ for $B_s \rightarrow \phi\phi$, whose branching ratio was unknown. The latter choice is equivalent to maximize the experiment potential to reach a 3σ observation of a new signal⁹. In the above expressions the background, B , is represented by appropriately normalized data selected in the same way as the signal except for requiring the two kaon invariant mass to be in the ϕ sideband region: $1.04 < m_{KK} < 1.06 \text{ GeV}/c^2$. The signal, S , is derived from a Monte Carlo (MC) simulation of the CDF II detector and trigger. For $B_s \rightarrow \phi\phi$ a blind analysis was performed. The signal region was hidden until after all the selection requirements were fixed and background evaluated.

$B^+ \rightarrow \phi K^+$ candidates are selected requiring: vertex goodness-of-fit $\chi^2 < 8$, decay length $L_{xy} > 350 \mu\text{m}$, B^+ reconstructed impact parameter $d_0^B < 100 \mu\text{m}$, non-trigger track transverse momentum $p_T^{soft} > 1.3 \text{ GeV}/c$ and impact parameter $d_0^{soft} > 120$

μm . We further require that $I_{R<1} > 0.5$, where I_R is defined as the ratio of the B^+ candidate p_T over the total transverse momenta of all tracks within a cone of radius $R = \sqrt{(\Delta\eta^2 + \Delta\phi^2)}$ around the B flight direction. Moreover, the reconstructed ϕ mass is required to lie in the interval $1 < m_{KK} < 1.06 \text{ GeV}/c^2$.

The signal yield and asymmetry are extracted simultaneously from an extended unbinned maximum likelihood fit on four discriminating variables (Fig. 1): the three-kaon invariant mass, m_{KKK} , the invariant mass of the ϕ candidate, m_{KK} , the ϕ helicity angle and the kaon dE/dx measured in the COT. Data are fit to seven categories: signal, partially reconstructed $b \rightarrow \phi X$ decays, combinatorial background, $B^+ \rightarrow K^{*0}(892)\pi^+$ and three B decay modes which peak in the signal region, including $B^+ \rightarrow f_0(980)K^+$ and non-resonant decays. The latter contributions are fixed by their relative decay rates and detection efficiencies to the $B^+ \rightarrow K^{*0}(892)\pi^+$ one, which is determined from the fit. A combination of Monte Carlo simulation and sideband data was used to model the signal and background shapes. The fit returns $N_{\phi K} = 47.0 \pm 8.4$, $A_{CP} = -0.07 \pm 0.17$ and $N_{K^{*0}\pi^+} = 7.8 \pm 6.0$ corresponding to a background from $B^+ \rightarrow f_0 K^+$ of 11%.

A similar fit uses $m_{\mu\mu K}$ and $m_{\mu\mu}$ on candidates selected in the same way as in the $B^+ \rightarrow \phi K^+$ analysis above but requiring the invariant mass of two muons within $100 \text{ MeV}/c^2$ of the J/ψ mass. The result is

$N_{\psi K} = 439 \pm 22$ and $A_{CP} = 0.046 \pm 0.050$, where the error is statistical only.

The $B^+ \rightarrow \phi K^+$ BR ratio is calculated as:

$$\frac{\text{BR}(\phi K^+)}{\text{BR}(\psi K^+)} = \frac{N_{\phi K}}{N_{\psi K}} \frac{\text{BR}(\psi \rightarrow \mu\mu)}{\text{BR}(\phi \rightarrow KK)} \frac{\epsilon_{\psi K} \epsilon_{\mu}}{\epsilon_{\phi K}},$$

where $\epsilon_{\psi K}/\epsilon_{\phi K} = 0.685 \pm 0.015$, derived from MC, represents the total detector efficiency ratio for the two channels. World average 4 ϕ , J/ψ and $B^+ \rightarrow \phi K^+$ partial widths are used. The muon efficiency, $\epsilon_{\mu} = 0.810 \pm 0.021$, is determined in a sample of inclusive J/ψ .

We define the CP asymmetry as:

$$A_{CP} \equiv \frac{\Gamma(B^- \rightarrow \phi K^-) - \Gamma(B^+ \rightarrow \phi K^+)}{\Gamma(B^- \rightarrow \phi K^-) + \Gamma(B^+ \rightarrow \phi K^+)}.$$

Systematic uncertainties on signal yield and asymmetry are evaluated by varying the parameterizations used in the likelihood fit, including the shape of the f_0 resonance. For the branching ratio determination we consider also the uncertainty on the relative detection efficiency, which is the dominant one, and add it in quadrature to the yield uncertainty. For A_{CP} we conservatively assign a 5% systematic uncertainty from charge dependent detector asymmetries using the statistical uncertainty on the $B^+ \rightarrow J/\psi K^+$ asymmetry. The results are reported in Table 1.

Table 1. Preliminary CDF results for $B^+ \rightarrow \phi K^+$ and $B_s \rightarrow \phi\phi$. The first uncertainty is statistical, the second systematic.

	$B^+ \rightarrow \phi K^+$	$B_s \rightarrow \phi\phi$
Yield	$47.0 \pm 8.4 \pm 1.4$	$7.3 \pm 2.8 \pm 0.4$
BR $\cdot 10^5$	$0.72 \pm 0.13 \pm 0.07$	$1.4 \pm 0.6 \pm 0.6$
A_{CP}	$-0.07 \pm 0.17^{+0.06}_{-0.05}$	—

The $B_s \rightarrow \phi\phi$ signal is selected requiring two kaon pairs with invariant mass within $15 \text{ MeV}/c^2$ of the ϕ mass. We then apply the following selection: vertex goodness-of-fit $\chi^2 < 10$, decay length $L_{xy} > 350 \mu\text{m}$, B_s reconstructed impact parameter $d_0^B < 80 \mu\text{m}$, the minimum momentum of the ϕ mesons $p_T^\phi > 2.5 \text{ GeV}/c$ and minimum impact parameter of the two kaons in each of the ϕ

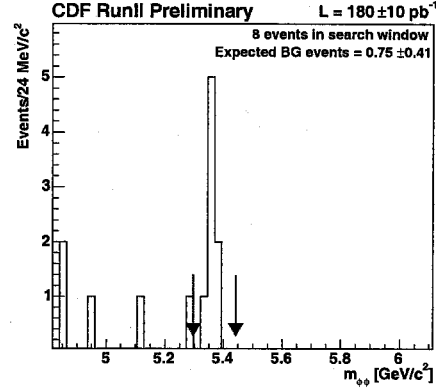


Figure 2. Invariant mass for $\phi\phi$ candidates.

mesons ($d_0^1 > 40 \mu\text{m}$, $d_0^2 > 110 \mu\text{m}$). The $B_s \rightarrow \phi\phi$ candidate invariant mass distribution is shown in Fig. 2. In a region of $\pm 72 \text{ MeV}/c^2$ around the B_s mass, a window three time the expected mass resolution, we count 8 signal candidates.

Two sources of background are expected: combinatorial background and $B_d \rightarrow \phi K^{*0}$ cross-feed with the pion from K^{*0} decay mis-identified as a kaon. The first type of background is studied using a background enriched sample where both ϕ meson candidates have invariant masses lying in the ϕ mass sideband region. Its contribution in the signal region was estimated as 0.35 ± 0.37 events. From Monte Carlo the expected $B_d \rightarrow \phi K^{*0}$ background is estimated as 0.40 ± 0.18 events. In both cases statistical and systematic uncertainties are included.

The probability of Poisson fluctuation of background to the observed number of events is less than $1.3 \cdot 10^{-6}$ corresponding to a 4.7σ significance. Adding the events that are selected uniquely by the prescaled trigger we find 12 signal candidates with 1.95 ± 0.63 background, corresponding to a 4.8σ significance.

A sample of $B_s \rightarrow J/\psi\phi$ is selected requiring one pair of kaons and one pair of muons within respectively 15 and 50 MeV/c^2 of the ϕ or J/ψ mass and criteria similar to

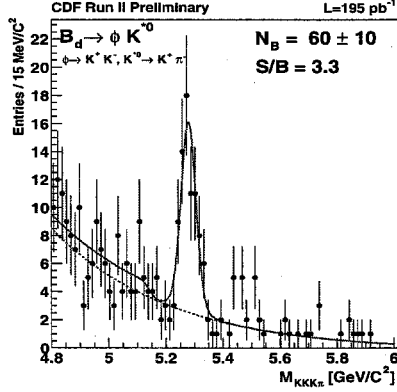


Figure 3. The invariant mass distribution for ϕK^{*0} candidates using 195 pb^{-1} of data.

the $B_s \rightarrow \phi\phi$ case on decay length and kinematics. A clean signal of $69 \pm 10(\text{stat.}) \pm 5(\text{syst.})$ $B_s \rightarrow J/\psi\phi$ events is extracted from a fit to the B_s invariant mass distribution. The systematic error is evaluated using alternative background models. From MC simulation we expect a background in the signal peak of 3.9 ± 1.7 events from $B_d \rightarrow J/\psi K^{*0}$ decays with a mis-identified kaon.

The $B_s \rightarrow \phi\phi$ decay rate is derived from:

$$\frac{\text{BR}(\phi\phi)}{\text{BR}(\psi\phi)} = \frac{N_{\phi\phi}}{N_{\psi\phi}} \frac{\text{BR}(\psi \rightarrow \mu\mu)}{\text{BR}(\phi \rightarrow KK)} \frac{\epsilon_{\psi\phi} \epsilon_{\mu}}{\epsilon_{\phi\phi}},$$

where $\epsilon_{\phi\phi}/\epsilon_{\psi\phi} = 0.816 \pm 0.015$ and $\epsilon_{\mu} \approx 0.92$. We use the world average ϕ and J/ψ branching ratios ⁴ and $\text{BR}(B_s \rightarrow J/\psi\phi) = (1.42 \pm 0.51) \cdot 10^{-3}$, obtained correcting the CDF measurement ¹⁰ for the current world average f_s/f_d ratio ⁴, to finally derive the result reported in Table 1.

The uncertainty on the $B_s \rightarrow J/\psi\phi$ yield extraction and background evaluation contribute 6.9% to the relative BR systematic error. The efficiency ratio is affected by uncertainties in the polarization of the decay vector particles and by theory uncertainty on $\Delta\Gamma_s$. We conservatively vary the longitudinal polarization of the $B_s \rightarrow \phi\phi$ decay from 0 to 100% and $\Delta\Gamma_s$ in the range $0 < \Delta\Gamma_s/\Gamma_s < 0.3$. Summing in quadrature all contributions we estimate a total relative systematic uncer-

tainty error on the $\text{BR}(B_s \rightarrow \phi\phi)$ of 14%. The uncertainty on $\text{BR}(B_s \rightarrow J/\psi\phi)$, 36%, is then the dominant one.

Thanks to the new displaced track trigger, CDF is accumulating high quality data on several other charmless decays. As an example, Fig. 3 shows the invariant mass of $B_d \rightarrow \phi K^{*0}$ candidates, reconstructed in a similar way as the $B_s \rightarrow \phi\phi$ above, with a signal of ~ 60 events and $S/B > 3$. It will allow precision measurement of polarization and nicely illustrates the CDF potential to exploit light vector resonances in B_s decays. With two to three times the data used here CDF should detect a signal of $B_s \rightarrow K^{*0} \bar{K}^{*0}$ with an expected ² BR of $\approx 3.7 \cdot 10^{-6}$.

In summary, we have shown the first evidence of $B_s \rightarrow \phi\phi$ and measure: $\text{BR}(B_s \rightarrow \phi\phi) = (1.4 \pm 0.6(\text{stat.}) \pm 0.2(\text{syst.}) \pm 0.5(\text{BR})) \cdot 10^{-5}$. For the $B^+ \rightarrow \phi K^+$ channel we measure the partial width and A_{CP} which agree with available measurements ⁴ within uncertainties.

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